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APPLICATION OF REMOTE SENSOR DATA
TO
GEOLOGIC ANALYSIS OF THE BONANZA TEST SITE
COLORADO

SEMIANNUAL PROGRESS REPORT
1 April - 30 September, 1972

Remote Sensing Report 72-7

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REMOTE SENSING PROJECTS

DEPARTMENT OF GEOLOGY

COLORADO SCHOOL OF MINES ♦ GOLDEN, COLORADO

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Compiled and Edited
by

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Semiannual Report, 1 April - 30 September, 1972

Compiled and Edited by
Keenan Lee

INTRODUCTION

This report summarizes the research activities of the Colorado School of Mines faculty and students and the Martin Marietta Corp. scientists for the period 1 April 1972 to 30 September 1972. During this period, Professors Keenan Lee and R. G. Reeves and graduate students D.L. Bruns, R.W. Butler, R.J. Eichler, L.H. Jefferis, D.H. Knepper, Jr., and R.W. Marrs of CSM, and research scientists R.C. Hulstrom, J.R. Muhm and K.E. Worman of MMC carried out research under the project.

ACQUISITION OF REMOTE SENSOR DATA

An aircraft support mission was requested for the C-130 during the report period. The mission was not flown.

PROGRESS REPORT ON GEOLOGIC REMOTE SENSING APPLICATIONS

Regional Geologic Mapping

Introduction

During the time period of this report, the final phase of this research program conducted under the Bonanza Project was begun. This phase consists of analyzing and synthesizing the research results of the past four years and preparing a final report. The final report will be published as a technical report and will contain sections on the stratigraphy, structural history, and mineral deposits of the study area, and a summary of the applications of remote sensing to regional geologic analysis. The stratigraphy section is currently in rough draft form; completion of the final report is targeted for March, 1973.

A summary of the study and the preliminary results to date are given below. Much of this summary has been extracted from a paper prepared during the period of this report and presented at the 8th International Symposium on Remote Sensing of Environment, University of Michigan, in October, 1972 (Knepper and Marrs, 1972).

A variety of remote sensor data has aided geologic mapping in central Colorado. This report summarizes the application of sensor data to both regional and local geologic mapping and presents some conclusions on the practical use of remote sensing for solving geologic mapping problems. It is emphasized that

this study was not conducted primarily to test or evaluate remote sensing systems or data, but, rather, to apply sensor data as an accessory tool for geologic mapping. All conclusions reached on the utility of the various sensor data and interpretation techniques for geologic mapping are by-products of attempts to use them.

The remote sensor data used in this study were acquired by the NASA Earth Observations Aircraft Program for the Bonanza remote sensing project (NASA Grant NGL 06-001-015) at the Colorado School of Mines. The type and quality of the data, therefore, are defined by the systems aboard the various NASA aircraft.

Study Area

No consideration was given to the particular "suitability" of the area for the application of remote sensing techniques. The area was chosen solely for its critical importance to the understanding of Cenozoic tectonic and geomorphic evolution in central Colorado. Consequently, the area deviates markedly from the concept of a geologic remote sensing "test site"-- an area characterized by its structural simplicity, highly contrasting rock types, excellent exposures, and easy access.

The area is centered along the Rio Grande rift zone, a major tectonic element of late Tertiary age, extending from southern New Mexico for some 600 miles northward into northern Colorado (Fig. 1). Within the study area the geology is complex and diverse. The structurally and topographically low San Luis and Arkansas valleys follow the internal portion of

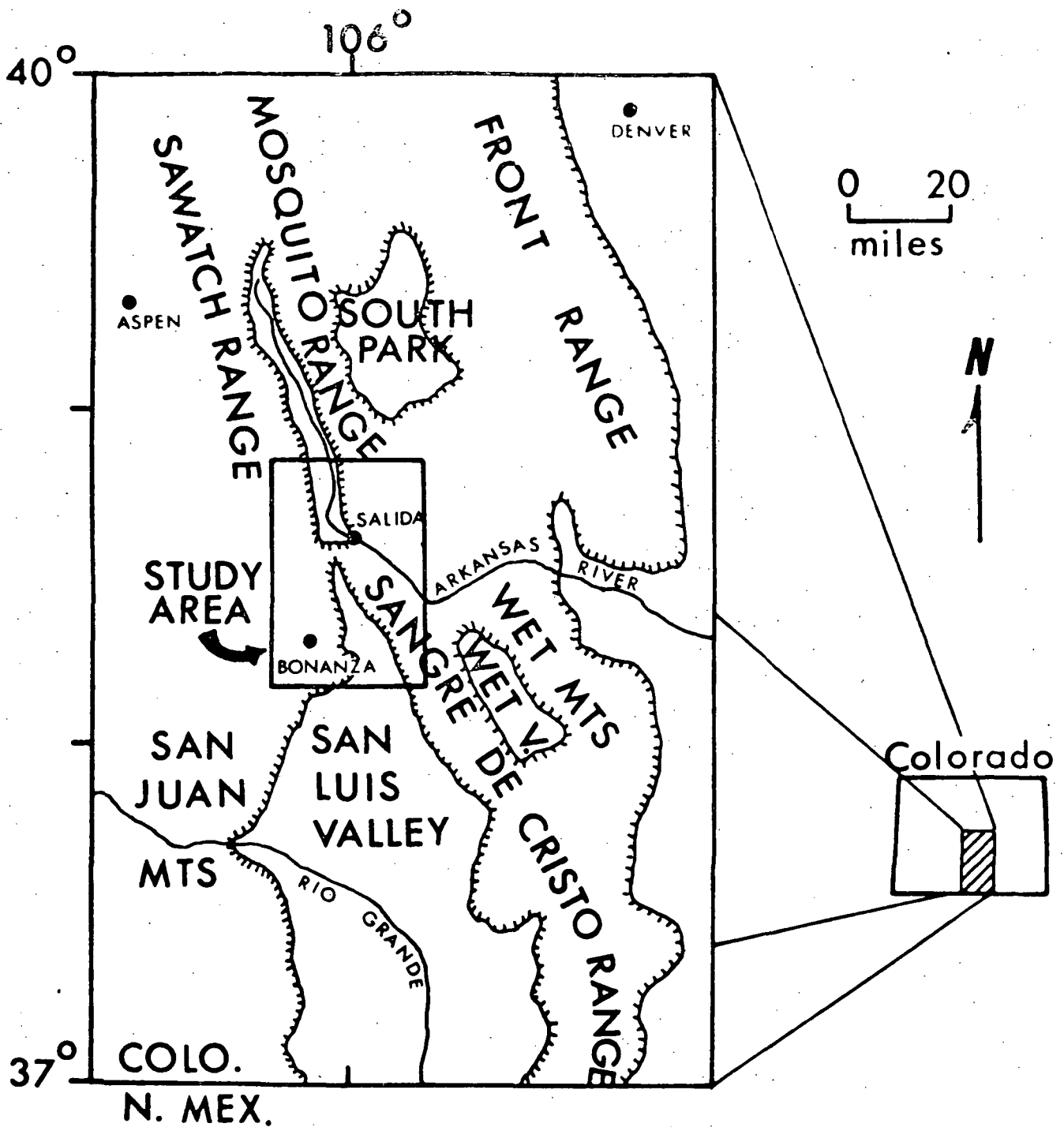


FIGURE 1. INDEX MAP OF STUDY AREA. Internal portion of Rio Grande rift zone extends northward from the northern San Luis Valley into Arkansas River Valley.

the rift zone. The valleys are filled with upper Tertiary clastic sediments shed from the bordering uplifts. The mountain ranges on the west and east are composed of Precambrian igneous and metamorphic rocks, complexly-deformed Paleozoic sedimentary rocks, and Tertiary igneous plutons. Oligocene volcanic rocks of the Bonanza volcanic field form the mountains in the southwestern part of the area (Knepper and Marrs, 1971).

Dense conifer forests and extensive alluvial and colluvial deposits cause constant problems in bedrock geologic mapping, both in the field and by the use of remote sensor data. Relief between valley floors and adjacent mountain peaks is commonly 4,000 feet, locally reaching as much as 7,000 feet. Vehicular travel is impossible in most of the rugged mountain terrain.

Methods

A primary element of this study has been the preparation of a geologic map, covering about 1,100 square miles, that could be used to interpret the complex tectonic and geomorphic history of this portion of the Rio Grande rift zone. Numerous structurally- and lithologically-controlled mineral deposits provided additional incentive for studying the structure, location, and distribution of the rocks and sediments of this area.

In many respects, this study has been similar to "standard" geologic mapping programs in which conventional air photos are used as a mapping tool; it differed, however, by its broader areal scope and wider use of remote sensor data. Effective application of remote sensing was critical because of the limited time available to complete the task.

The study started with library research and the compilation of previous geologic mapping within, and bordering, the area. A map scale of 1:62,500 was chosen to accommodate the necessary detail while maintaining a workable size. From the remaining unmapped area, several subareas were selected for detailed and reconnaissance field mapping. Selection of these subareas was based on the following considerations:

- 1) Projection of major structural trends from previous mapping,
- 2) geologic analysis of small-scale color and color infrared photographs (1:100,000), and 3) isolation from previously mapped areas.

Detailed studies of local areas within the study region provided an opportunity to accumulate a working knowledge of how the various lithologic, structural, and geomorphic features were expressed on the sensor data and develop efficient interpretive methods and techniques. Concurrent detailed mapping by other investigators yielded additional ground data as the study progressed.

The areas mapped in the field provided a network of ground control scattered throughout the study area. Mapping the intervening areas was accomplished by geologic interpretation of a variety of remote sensor data, supplemented by frequent field checks. Special enhancement and processing techniques were applied to selected pieces of sensor data in an attempt to decrease interpretation time (expense) and extract added geologic information.

Geologic features (faults, fractures, contacts, fold axes) were traced on clear acetate overlays, and final interpretations were transferred to 1:62,500 topographic base maps, a separate

map being used for each type of sensor data. A preliminary geologic map of the entire study area was made by compiling all the geologic mapping data, including previous and current field mapping and remote sensor data interpretations, on a 1:62,500 topographic base map. Field checks were made in selected areas, particularly where structural interpretation or lithologic identification was questionable or conflicting. A final geologic map was constructed including appropriate modifications.

Sensor Data

NASA missions 101, 105, 168, and 184 provided a variety of remote sensor data over the study area. High-altitude color and color infrared (IR) photographic coverage (1:100,000) is nearly complete. Low-altitude color and color IR photography at scales ranging between 1:12,000 and 1:24,000 was obtained over nearly 80 percent of the area.

Four-band multiband photography (both high- and low-altitude) and daytime and pre-dawn thermal IR imagery (3-5 μm and 8-14 μm) were flown in selected areas. Brute-force and synthetic-aperture side-looking airborne radar (SLAR) at various polarization combinations was acquired over a large part of the area, and low sun-angle photography (LSAP) was obtained in the northeastern and eastern parts of the area. Thermal IR spectrometric, microwave radiometric, and radar scatterometric data were acquired on a few lines, but these data have had no application to this investigation. Ground control data were gathered during each mission to aid in the interpretation process.

Sensor Data Applications

Photographic data were used extensively in the geologic mapping. High-altitude color and color IR photography (1:100,000) was extremely useful in placing local areas into proper regional geologic and geographic perspective. Its primary use, however, was for delineating and tracing regional structural features and locating potential problem areas.

Low altitude color and color IR photography (1:12,000 to 1:24,000) was the primary mapping tool. The low-altitude photography was used both in the field as an aid in detailed and reconnaissance mapping and also in the laboratory to map details of local geologic features identified on high-altitude (small scale) photography. Low-altitude photography was invaluable in extending geologic mapping from geologically known into unknown areas in the detail necessary for this study, and in further restricting problematical areas for subsequent field visitation.

Low sun-angle photography (B/W IR with W 25 filter) proved extremely useful for mapping the distribution of nine levels of Quaternary pediment and stream terrace gravel in the Arkansas River Valley. The gravel surfaces are defined by their height above modern stream base and above each other; shadowing produced by low sun-angles enhances the topographic differences, making surface detection and mapping easier and faster than with conventional high sun-angle photography. In addition, a relatively large photographic scale (1:24,000) and moderate sun-angle (24° - 27°) increases the utility of the LSAP for mapping textural differences between surface materials. However, the large scale

and moderate sun-angle decreases the utility of the LSAP for structural studies because, 1) subtle, topographically-expressed structures are disguised in a maze of detail; and 2) only small segments of major structural features are imaged in a single photograph, making recognition and identification difficult.

High-altitude multiband photography was examined in several areas. An extremely small scale, combined with over-all poor photo quality (overexposure) rendered the high-altitude multiband photography inadequate for this investigation.

Low-altitude multiband photography was examined in several areas of known geology to determine whether it contained a significant amount of geologic information over and above the information extracted from simultaneously-obtained color and color IR photography. Each of the four bands (standard blue, green, red and IR film/filter combinations) of photography was studied by conventional photographic techniques, using stereoscopic analysis where possible. In general, the "new information" content of the multiband photography was very low and interpretation time quite long. Consequently, multiband photography was considered impractical for this investigation.

Thermal IR scanner imagery (8-14 μm and 3-5 μm), obtained over areas of known geology during pre-dawn and daytime flights, was analyzed. Some new geologic information, not previously discovered during field mapping or photo interpretation, was extracted from the imagery, but the information was of minor consequence to the mapping program. In general, the inability to recognize and interpret known geologic features with certainty,

coupled with the relatively poor spacial resolution, inherent image distortion, and non-stereo-viewing characteristics of the data, made use of the thermal IR imagery in geologically-unknown areas tenuous. Thermal IR imagery is not considered a routine geologic mapping tool in this area.

SLAR imagery has thus far been sparingly used. The imagery is generally of poor quality (low resolution, flat contrast, frequent image disruption) and does not justly represent the potential of SLAR imagery for regional structural analysis. Analysis of a few fair-quality images suggests that good quality, high-resolution SLAR imagery of the entire area would have aided in delineating and mapping major topographically-expressed structural features at an early state of the study. This would, of course, have allowed areas for detailed field and photostudy to have been more judiciously chosen.

Several image enhancement techniques, including digital and video image processing and color additive viewing, were applied to selected pieces of color, color IR and multiband photography and thermal IR imagery. The major goals of image enhancement were (1) detection of linear features, and (2) discrimination of rock types. Although both goals were realized with varying degrees of success, equivalent detection and discrimination could generally be made by inspection of the original imagery data. In addition, machine processing gave equal importance to geologic and non-geologic phenomena alike, a situation avoided by human interpretation on the original imagery data. Image enhancement techniques, for the purpose of this study, were therefore judged impractical due

to expense, time, and low "new information" return.

Discussion

Probably the single greatest factor affecting the actual application of remote sensing to this geologic mapping study was the balance between 1) interpretation time and 2) significant geologic information derived from the interpretation. Time constraints forced concentration on the data providing the most information in the shortest interpretation time (i.e.-most useful data). The relative usefulness of the various types of data was determined subjectively by attempting to use the data for geologic mapping; results are shown in the following table:

RELATIVE USEFULNESS OF REMOTE
SENSING DATA USED IN THIS STUDY.
NUMBER 1 IS MOST USEFUL, ETC.

1. Low-altitude color photos
2. Low-altitude color IR photos
3. High-altitude color IR photos
4. High-altitude color photos
5. Low sun-angle photos
6. SLAR
7. Multiband photos
8. Thermal IR imagery

Low-altitude color and color IR photography contained the greatest amount of easily extractable geologic information. Low-altitude color photography was judged slightly better than color IR photography because the "natural" color presentation of the photographed scene was generally more useful than the information recorded from the photo IR portion of the spectrum. In some instances, however, geologic features noticed on color photography were enhanced on corresponding color IR photos. For example, linear groves of aspen trees associated with fault-controlled

springs were greatly enhanced on color IR photography due to their high reflectivity in the near IR as compared to the conifers in the same immediate area.

High-altitude color and color IR photography is considered the next most useful type of remote sensor data for detailed geologic mapping. Minus-blue filtration (standard in color IR photography) eliminated much of the blue scattering problem caused by the long air path (50,000 feet). The resulting color IR photos are significantly sharper than corresponding color photos and, hence, contain more extractable geologic information in spite of the "false color" presentation.

The remaining types of remote sensor data, with the possible exception of SLAR imagery, were judged impractical or inappropriate for broad-scale general geologic mapping. These data may be useful for solving specific problems in relatively small areas, but acquisition of the data can only be justified if the problem is thoroughly defined beforehand and preliminary studies dictate the need for unconventional remote sensor data. Although not a primary mapping tool, high quality SLAR imagery would probably be desirable for broad-scale geologic mapping programs, particularly in the early stages.

The importance of field investigations concurrent with the interpretation of remote sensor data cannot be overemphasized. Without associated field work, significant interpretative detail was lost and frequent geologic ambiguities developed. Spot lithologic identification of selected outcrops provided valuable interpretative information. Detailed geologic mapping of rela-

tively small areas within the region was even more productive since geologic interpretations could generally be extended into the surrounding unknown area using remote sensor data. By establishing sufficient field mapping subareas, much of the remaining area could then be mapped accurately and in great detail utilizing the sensor data to tie subareas together.

Completion of a detailed geologic map of the study area within the limited amount of time available (3 years) could not have been accomplished without the aid of remote sensor data, particularly the photography. The sensor data provided a means for mapping broad areas rapidly and accurately, and greatly helped to restrict problematical areas to specific sites which could be visited in the field.

The heavy reliance on the application of standard photographic techniques in this investigation is not necessarily indicative of the potential of unconventional photographic and non-photographic data for geologic mapping. Rather, it means that standard aerial photography (color, color IR, panchromatic) is more widely applicable at the present state-of-the-art of practical or operational remote sensing for geologic mapping. The need for continued research and development of remote sensing data acquisition, reduction, and interpretation techniques is very clear -- particularly for the less-common sensors--if the full potential of remote sensing is to be effectively applied to regional geologic mapping.

Future Plans

The results of the regional mapping project just described

will be correlated with other geologic mapping in the Bonanza Test Site and compiled on to a geologic map of the test site at a scale of 1:250,000. For the compilation project, the remote sensing interpretation criteria derived from this, and other, studies will be used to map remaining unknown areas within the test site on remote sensor data. The final product will serve as a basic test site for the evaluation of ERTS and EREP data.

Detailed Geologic Mapping

Research work in the Buena Vista area for this period included work in the following general areas:

1. Laboratory work involving the extraction of geologic information from remote sensor data,
2. Field checks of the laboratory results to determine the degree of accuracy of the interpretation, and
3. Comparison of field and laboratory data and evaluation of remote sensor data for geologic investigations.

Laboratory Work

Laboratory work on remote sensor data was started in the fall of 1971 on data from Missions 168 and 184, and continued through the spring of 1972. Data from each sensor were studied (including color, color IR, multiband and low sun-angle photography, and SLAR and thermal IR imagery), and geologic maps were constructed from each type of data, giving an interpretation of the rock distributions and fracture patterns. These maps were constructed on a USGS 1:24,000 topo base for comparison with previously drawn geologic maps of the study area.

Field Checks

Field work was begun in late May to determine the accuracy of the laboratory interpretations. This step was necessary because the degree of accuracy needed to check the remote sensor interpretation far exceeded that provided on the geologic maps drawn from the field work in the initial stages of the project in many areas. This field work continued through the months of June, July and half of August. It was found during this stage of the study that having the laboratory interpretation in hand during

field work greatly speeded the work and gave a more accurate final map than would have been provided by mapping on prints in the field.

Comparison and Evaluation

This phase of the study was started after the field season. The initial step was the construction of a final geologic map prepared from a compilation of all available knowledge on the area, from remote sensor data and field investigations. This provided a basis for the evaluation of the various sensor systems for geologic problems. Table 1 shows an evaluation of the sensors for fracture analysis for this area, and Table 2 shows a list for rock discrimination capability. Table 3 indicates a final evaluation of the sensors for detailed geologic mapping. This table indicates the preference (for this area) if only one sensor were to be used in a study. If two or more sensors were to be employed, the order of preference would be as shown in Table 4. In general, all the photographic systems were found to contribute valuable geologic data, and the imagery was found to be especially valuable when used in conjunction with photography.

TABLE 1

FRACTURE ANALYSIS EVALUATION

(best)	1	Large-scale color and color IR photos*
	2	Thermal IR imagery
	3	SLAR imagery
	4	small-scale color and color IR photos
	5	multiband and black and white prints

*Although low sun-angle photography was studied for the area, and would undoubtedly provide excellent fracture data, the photos obtained for this area were flown too late in the day to obtain a low enough sun angle to emphasize the lineament patterns.

TABLE 2

ROCK DISCRIMINATION EVALUATION

- 1 Large-scale color and color IR photos
- 2 Small-scale color and color IR photos
- 3 Multiband photography
- 4 Black and white prints
- 5 Thermal IR and SLAR imagery

TABLE 3

FINAL EVALUATION

- 1 Large-scale color and color IR photos
- 2 Small-scale color and color IR photos
- 3 Low Sun-angle and black and white prints
- 4 Thermal IR and multiband photography
- 5 SLAR imagery

TABLE 4

ORDER OF SELECTION WITH MORE THAN 1 SENSOR

- 1 Color and color IR photos (scale depends on area size, time available, data needed etc.)
- 2 Thermal IR imagery
- 3 SLAR imagery
- 4 Low Sun-angle photography
- 5 Multiband

Plans

An additional step is being carried out at present that involves a further examination of the remote sensor data, now that a knowledge of detailed field geology has been acquired, to determine if additional geologic information is available.

Report writing was also started near the end of the field season and continues to date. It is projected that a first draft of the technical report will be completed in February 1973.

Volcanic Studies - Bonanza Caldera

Introduction

A program for evaluating remote-sensing techniques as tools for geologic mapping in volcanic terrain has been under way at the Colorado School of Mines for the past three years. A technical report on this study will be published in the near future; the following is a summary of the results.

Data tested in this evaluation include color and color infrared photography, multiband photography, low sun-angle photography (LSAP), thermal infrared scanner imagery, and side-looking airborne radar (SLAR). Details on the use and evaluation of each of these sensors will be included in the technical report.

Remote Sensing Evaluation

The relative utility of color and color infrared photography was tested in several ways: the photos were used to refine geologic maps in previously mapped areas, they were used as field photos while mapping in the field, and they served in making photogeologic maps prior to field mapping. The latter technique, which was used as a test of the maximum utility of the photography, was successfully used to locate 75% of all faults in a portion of the geologically-complex Bonanza volcanic center and to map and correctly identify 93% of all Quaternary deposits and 62% of all areas of Tertiary volcanic outcrop in the area.

Attempts were made to enhance geologic contrasts and increase the capability of detecting and delineating lithologically and structurally important features using multiband photography. These were generally unsuccessful in the volcanic

terrain of the Bonanza area. Color additive viewing of the multiband photography also failed to produce any obvious contrast improvement.

Daytime thermal infrared imagery is useful for locating faults in spite of strong interference from topographic effects. Pre-dawn thermal imagery is also dominated by topography in areas of high relief, but shows very distinct moisture and vegetation patterns in areas of low relief. Some of these patterns were found to be geologically significant.

Low sun-angle photography is superior to DPD-2 side-looking radar in the Bonanza volcanic center, where the main objective of low-angle illumination is enhancement of topographically expressed structures. The low sun-angle photography has its major advantage in superior resolution, but lacks the flexibility of side-looking radar with regard to look-direction. For both sensors, the best illumination direction is one which is very nearly perpendicular to the structural trends and looks down the dominant topographic slope.

Geologic Results

Geologic mapping was done in conjunction with the remote-sensing evaluations in the previously unmapped area to the west of the central Bonanza mining district. This mapping confirms the existence of the Bonanza caldera and demonstrates that structures related to the caldera are the dominant features of the area.

The Oligocene volcanic sequence in the Bonanza area is typical of volcanism in and around the San Juan volcanic field.

It begins with intermediate andesitic flows and breccias, followed by more silicic pre- and intra-caldera lavas and ash-flows, and terminates with small, latitic and rhyolitic flows. Caldera collapse is associated with the eruption of the middle ash-flow sequence that serves as a geologic marker for the structural interpretation and as an indicator of the geologic evolution of the magma that produced the Bonanza volcanic pile. Interpretation of the major structural pattern of the Bonanza area as a collapse feature is based on the observed structural and stratigraphic relationships and is supported by gravity data.

The radial and concentric pattern of faulting which resulted from collapse of the Bonanza caldera has largely controlled the post-volcanic ore deposition. Mineralogical similarities among deposits demonstrate that mineralizing fluids moved out along radial fractures. The largest areas of alteration and mineralization are located at the intersections of the major radial and concentric trends.

Evidence of post-caldera movements on the west boundary fault of the Bonanza caldera and the coincidence of the west boundary fault of the caldera with the west boundary fault of the Arkansas Valley graben indicates that the caldera fault system has been undergoing additional displacement as a part of the presently active Rio Grande rift system. This late movement helps to explain why the west boundary of the Bonanza caldera shows more structural displacement than the east boundary.

Plans

A technical report covering these volcanic studies is in draft form. Publication is anticipated by May, 1973.

Fracture Studies

Introduction

Past research has demonstrated the capability of photo-interpretation and imagery enhancement to extract many linear features from photos and imagery, which are referred to as "photo-lineaments". In many cases these photo-lineaments correspond to known geologic fractures; in some cases they have no geologic significance; and in probably the majority of cases, their geologic significance is unknown. Research has begun to improve methods of photo-lineament interpretation and to determine some of the criteria for recognition of geologic faults and joints. Initial efforts have been oriented toward a photographic technique for enhancing photo-lineaments, as summarized below.

Photo-masking Enhancement

The ability of a photointerpreter to analyze an aerial photograph for geologically significant photo-lineaments is improved by masking techniques. These techniques are simple to perform and can be done in most darkrooms.

The masking technique consists of (1) making a sharp photo mask by contact reproduction on film of either a positive or negative aerial transparency, (2) sandwiching the resulting positive and negative with a small translational offset, and (3) printing the sandwich onto high contrast paper. The process is essentially an edge enhancement technique similar to that used for many years to create bas-relief effects from normal photographs. This process is not to be confused with unsharp masking or tone-

line processes, which themselves offer promise for enhancing photo-lineaments.

Preliminary analysis of masked aerial photos demonstrates two conclusions of geologic significance: (1) linear geologic structures, such as faults, fractures, dikes and hogbacks, may be enhanced by masking; and (2) secondary geologic structure, referred to as regional fabric and consisting largely of minor faults, jointing and/or stratification, is definitely enhanced by photo masking.

D. Wise and other researchers have demonstrated the potential use of simulated low sun-angle photography (LSAP) using raised relief models for showing geologic structure. When these techniques were applied to a relief model of the Trinidad, Colorado, quadrangle, 50 of the 163 known, mapped faults of the area were picked by interpretation of the simulated LSAP, including all of the major faults. However, 8 different illumination directions were required, since no single direction was capable of showing all, or even most, of the lineaments. Masking of only one LSAP simulation photo (south illumination, 20°), however, yielded detection of 51 of the known faults, and in addition provided considerably more geologic fabric information. This by itself is no large improvement, but for real-life geologic investigations it is significant, because aerial photography does not have the capability of obtaining LSAP from all directions, and generally only one illumination direction is available.

Plans

Research on the sharp-masking technique is continuing during

the present six-month period. Currently, emphasis is being placed upon a more rigorous quantification of the results to date, after which attention will be directed toward applications of the technique to areas in and near the Colorado Mineral Belt.

Computer programs to quantitatively analyze fracture and photo-lineament data are being adapted for the CSM PDP-10 computer. Such programs will not only aid in the statistical analysis of these data, but will enable correlations between the two types of data to be made.

Surficial and Engineering Geology

Introduction

Research activities to date have consisted primarily of detailed geologic mapping, sampling, and laboratory investigations of the test site during the summer and fall of 1972.

Test Site

The test site is in the eastern portion of the Bonanza Test Site, approximately 3 miles north of Colorado Springs and immediately east of the U.S. Air Force Academy. The site covers approximately 46 square miles, in parts of Pikeview and Falcon NW 7½' quadrangles (Fig. 2).

The area consists primarily of rolling hills of Quaternary sand dunes and pediment gravels on a Tertiary bedrock surface that is dissected by westward-flowing streams draining into Monument Creek. Vegetation is mostly short grass in the dune area, with good timber development to the north in the Black Forest and to the south on Austin Bluffs. The average elevation is 7000 ft. above sea level.

The two sand dune forms which prevail in this area are longitudinal and parabolic. The longitudinal dunes vary in length from approximately 100 to 5000 ft and average approximately 10 ft in height. The dunes generally trend N 60 E and are deposited on the smooth, gently-sloping Pine Valley Gravel surface. Several of these dunes are bisected by Interstate Highway 25 and Colorado Highway 83.

The parabolic dune field is in the center of the test site and south of the longitudinal dune field. The limbs of these

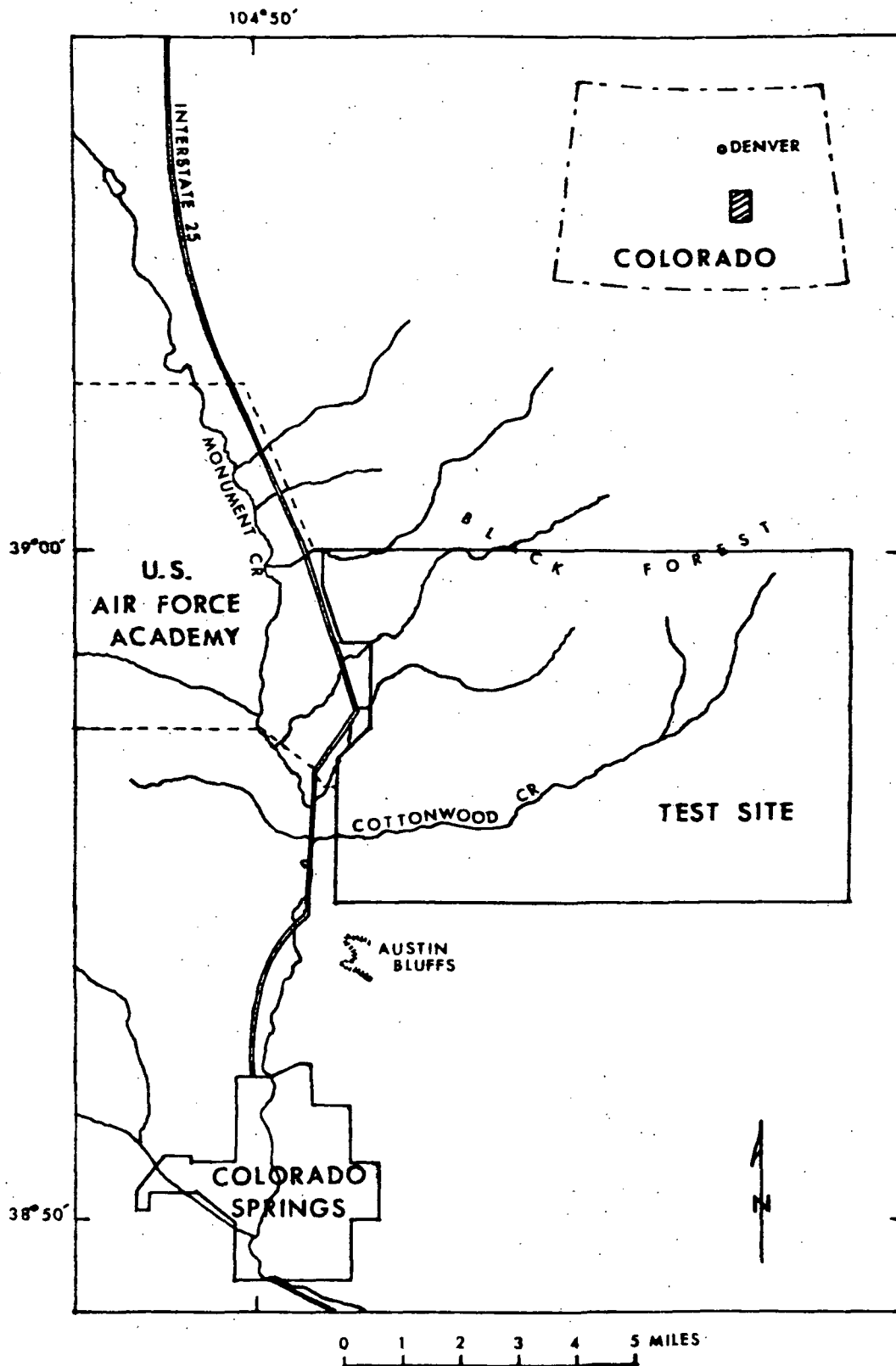


Figure 2. Index map of the LSAP experiment test site.

dunes vary in length from approximately 50 to 500 ft and may range in height from 0 to 30 ft. The parabolic dunes are oriented in a general east-west direction and also overlies the Pine Valley Gravel and the Dawson Arkose. Both dune forms of the test site are recently stabilized and sparsely vegetated.

The relative abundance and variety of geomorphic features in the test site make it quite suitable for a low sun-angle photography (LSAP) study, and the area has been so proposed. The purpose of the LSAP experiment will be to determine the optimum sun azimuths, illumination angles, and photographic scale necessary to enhance low-relief geomorphic features. The specific area of interest is a 15 square mile Quaternary sand dune field overlying the Tertiary Dawson Arkose and the Quaternary Pine Valley Gravel immediately east of Interstate Highway 25.

Previous LSAP studies have been concerned primarily with the determination of optimum sun azimuths and illumination angles for the enhancement of local or regional structural features, such as folding, faulting, and jointing in areas of moderate to high relief. LSAP investigations by Hackman (1967) suggested that both high and low sun-angle photographs be used for photointerpretation studies and that a sun-angle of 20 to 30 degrees was the most satisfactory if only one set of photographs could be taken. Similarly, Wise (1969) sought to evaluate optimum sun-angles and illumination azimuths for the purpose of enhancing topographic linears of relatively high-relief areas. Optimum LSAP conditions for structural analysis were also investigated by Lyon and others (1970), but again

the emphasis was placed on the evaluation of moderate- to high-relief terrain.

Plans

To date, only the mission planning phase of the LSAP experiment has been completed. The low sun-angle photography was requested from NASA, but it was not obtained (see "NASA Aircraft Missions", p. 2). The photography will now be sub-contracted. Three north-south flight lines will be used to provide coverage of the test site at 1:12,000 and 1:24,000 scales. In order to create a basis for comparison of the different photo scales, sun angles, and azimuths of illumination, the mission will be flown on two separate days. The first day the aircraft will fly all lines at 6000 ft above terrain, every 2 hours from 0700 to 1500 hours sun time, thus providing varying sun angles for 2 azimuths of illumination (east and west). Similarly, on the second day the aircraft will fly at the same times at 12000 ft above terrain to provide the smaller scale coverage. All photography will be flown using black and white infrared film (type 2424) with a Wratten No. 25 filter to provide maximum darkening of the terrain shadows.

It is anticipated that information gained from this study will provide quantitative data to benefit future LSAP missions oriented toward low-relief terrain enhancement for surficial geologic studies.

Mineral Deposits

Introduction

This is a summary of the investigation of the application of remote sensing to the problems of geology and mineral exploration in the vicinity of Leadville, Colorado, from 1 April through 30 June, 1972. After that time period, this work was transferred and continued as part of the ERTS project.

The time period was spent in interpreting available remote sensor data and in initial field checking of the results of that interpretation. This work represents a continuation of work reported on in greater detail in the preceeding report (Applications of Remote Sensor Data to Geologic and Economic Analysis of the Bonanza Test Site, Colorado; Semiannual Progress Report, October 1, 1971 - March 31, 1972, Remote Sensing Report 72-4, May, 1972) which was prepared during the time period covered by this report.

Data Analysis

Field checking in the Granite mining district (Lake and Chaffee Counties, Colorado) tended to verify the fault/fracture pattern mapped in that area from remote sensor data. Areas mapped as intrusives were found to be rhyolite dikes, and areas mapped as alteration were found to be altered. In addition, a strong layering within the Precambrian metamorphic rocks was observed in some areas. This layering consisted of changes in lithology from biotite-poor gneiss to biotite-rich gneiss or schist and produced topographic, vegetational, and color variations which should have been apparent on low-altitude photography. Use was made of the interpretation table and zoom stereoscope.

available at Martin Marietta Corp., and it was found that under high magnification this layering could be seen, and strike and dip, folds, and sometimes offset across faults could be mapped. This layering probably represents pre-metamorphic sedimentary bedding. Photographic interpretation together with field checking during and after this report period also outlined a transitional contact between the gneiss and schist with intrusions of granite, and the massive Precambrian granite with remnants of engulfed gneiss and schist which forms the crest of the Mosquito Range in this area.

Correlation of mines and prospects in the Granite mining district with the fracture pattern, lithology, and alteration as mapped by remote sensing (supplemented by field checking), indicates that most alteration and mineralization in the Granite mining district were structurally controlled by the faults and fractures and were apparently restricted, stratigraphically, to the Precambrian gneiss and schist. Most mineralization occurred along the faults and fractures, though in a few cases alteration and mineralization occurred in a favorable layer within the gneiss and schist. Very little alteration or mineralization was found in the Precambrian granite. Additionally, the most intensive alteration and mineralization occurred in areas where northeast and northwest trending faults/fractures intersect.

In summary, remote sensing has been used to map the structural and stratigraphic controls of mineralization and alteration in an area for which such information was not previously available. In addition, several large areas of alteration were identified

from color aerial photography. Thus information has been obtained primarily from remote sensing which would be extremely useful to any mineral exploration program carried out in the Granite mining district. Much of the fault/fracture pattern mapped would have been extremely difficult to map solely by field work done without reference to aerial photography, as in most cases the only field evidence for faulting was the presence of springs along the faults and occasional fragments of brecciated Precambrian gneiss in the vicinity of the faults. This lack of field evidence is due to the presence of a residual soil over much of the Precambrian rock and to the uniformity of rock type in the area.

Plans

This study will continue under the ERTS-A project. A final report will summarize the aircraft remote sensing applications to mineral deposits derived from this study to date, as well as a comparative evaluation of aircraft and ERTS data for mineral deposits exploration.

GEOLOGIC REMOTE SENSING EDUCATION

Faculty working under this grant have developed three graduate courses in geologic remote sensing (Lee, 1972, p. 43-1). During the current semester, the first course of the trilogy, Introduction to Remote Sensing, is being offered as part of CSM's Continuing Education Program, in which courses are available to professional people working in the Denver metropolitan area. Enrollment at present totals 21, including 11 CSM graduate students, 2 graduate students from other universities, and 8 professional scientists.

PAPERS PRESENTED

Remote Sensing Aids Geologic Mapping, D.H. Knepper, 8th Intl. Symp. Remote Sensing of Environment, Ann Arbor, Mich., 5 Oct. 1972.

Bonanza Project - 1971, Keenan Lee, 4th Annual Earth Resources Program Review, NASA/MSC, 18 January 1972 (not reported last Semi-annual Progress Report).

Bonanza Project Research at Martin Marietta Corp. - 1971, J.R. Muhm, 4th Annual Earth Resources Program Review, NASA/MSC, 18 January 1972 (not reported last Semi-annual Progress Report).

Application of Remote Sensing Techniques to Geologic Mapping in the Bonanza Volcanic Center, Saguache County, Colorado, R.W. Marrs, 25th Ann. Mtng., Geol. Soc. America, Rocky Mtn. Sec., Laramie, Wyo., 11-13 May 1972.

PAPERS PUBLISHED

Knepper, D.H., and Marrs, R.W., 1971, Geological development of the Bonanza - San Luis Valley - Sangre de Cristo Range area, south-central Colorado, in Guidebook of the San Luis Basin, Colorado: N. Mex. Geol. Soc., 22nd Ann Field Conf., p. 249-264.

_____, Remote sensing aids geologic mapping: Proc. 8th Intl. Symp. Remote Sensing Environment, U. Mich., Ann Arbor (in press).

Lee, Keenan, 1972, Bonanza Project - 1971: Proc. 4th Ann. Earth Resources Program Rev., NASA, MSC - 05937, V. 2, p. 43-1 to 43-23.

Marrs, R.W., 1972, Application of remote sensing techniques to geologic mapping in the Bonanza volcanic center, Saguache County, Colorado [abs.]: Geol. Soc. America Abstracts, v. 4, n. 6, p. 390-391.

REFERENCES

- Hackman, R.J., 1967, Time, shadows, terrain and photointerpretation: U.S. Geol. Survey Prof. Paper 575B, p. B155-B160.
- Knepper, D.H., and Marrs, R.W., 1971, Geological development of the Bonanza-San Luis Valley-Sangre de Cristo Range area, south-central Colorado, in Guidebook of the San Luis Basin, Colorado: New Mex. Geol. Soc., 22nd Ann. Field Conf., p. 249-264.
- _____, 1972, Remote sensing aids geologic mapping: Proc. 8th Intl. Symp. Remote Sensing of Environment, U. Mich., Ann Arbor (in press).
- Lee, Keenan, 1972, Bonanza Project - 1971: Proc. 4th Ann. Earth Resources Program Rev., NASA, MSC - 05937, v. 2, p. 43-1 to 43-23.
- Lyon, R.J.P., Mercado, J., and Campbell, R., Jr., 1970, Pseudo radar: Photog. Eng., v. 36, no 12, p. 1257-1261.
- Wise, D.U., 1969, Pseudo-radar topographic shadowing for detection of subcontinental sized fracture systems: Proc. 6th Intl. Symp. Remote Sensing of Environment, U. Michigan, Ann Arbor, v. 1, p. 603-615.

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